XIV. What Next?

Questions are better than answers.

Detailed study of Martian meteorites has helped perfect analytical techniques and reformulate questions about the geological processes that have occurred on Mars. The results of the studies on meteorites reported in the preceding chapters now need to integrated with the observations from spacecraft that have gone to Mars - especially Viking, Pathfinder and Surveyor missions and with planning for future sample return from Mars. Such a synthesis is beyond the scope of a compendium, but some unanswered questions, lessons learned, and other topics are listed below, along with a few key references, as a point of departure for pilgrims planning to embark on this journey.

Mars Sample Return

Close-up photographs of rocks and soils taken by both Viking landers and by the Pathfinder lander and Sojourner rover have inspired the scientific community to evaluate what could be learned from a sample that might be returned from the surface of Mars (Brett, 1974; Gooding, 1990; Longhi, 1996; Bogard, 1996). In 1987, a workshop on Mars sample return science was held at the Johnson Space Center (Drake *et al.*, 1987) and another discussion was held in Europe (Jessberger, 1991). Recently, another workshop, titled "Mars 2005: Sample Return Workshop", was held at Ames Research Center (Gulick, 1996). Currently (1998), a committee led by Mike Carr, termed Mars Sample Handling and Requirements Panel (MSHARP), has been charged with planning the requirements for sample return and precursor missions.

Rationale for sample return from Mars has been articulated by Bogard *et al.* (1979), Gooding *et al.* (1989), Allen and Treiman (1995), Allen (1996) and others. Wright *et al*. (1994) made the interesting case for a sample of sedimentary rock, which, so far, has not been found in the meteorite collection. However, a lengthy report titled "An Exobiology Strategy for Mars Exploration" by Kerridge *et al.* (1995) generally overlooked the great potential of sample return and/or the careful study of Martian meteorites. Issues and recommendations related to the return of a Martian sample to Earth have been discussed by the National Academy of Science (Nealson *et al.,* 1997).

Water

"Water" on Mars has been said to be the unifying theme of NASA's Mars Surveyor Program. The Global Surveyor will survey the surface for hydrous minerals, and two rovers in 2001 and 2003 will collect samples. A sample return mission in 2005 will return the samples to Earth in 2007. It is anticipated that the landing sites will be picked where there is the best change of finding evidence of "water" and ancient "life" on Mars (Carr, 1996; Edgett and Parker, 1997). In their recent paper, Edgett and Parker argue that "*a vast portion of the Martian ancient cratered terrain was once under water*". This is interesting in light of the current studies of the ancient meteorite, ALH84001 *(see Chapter X)* (Warren, 1998; McSween *et al.*, 1998).

Water has been found in Martian meteorites (Kerridge, 1988; Karlsson *et al*., 1991, 1992; Leshin *et al.*, 1996c). In addition, hydrous minerals have been reported (Trieman, 1983). However, the phosphates do not seem to indicate that much water was present when magma crystallized. The salts found in Martian meteorites have already given us a tantalizing clue about the nature of water on the surface of Mars (Gooding, 1992; Warren, 1998). The weathering product "iddingsite" found in Lafayette (Treiman and Lindstrom, 1997) has been tentatively dated at about 700 Ma (Swindle *et al.*, 1997; Shih *et al*., 1998).

Analogs and Simulants

Geological processes that have occurred on Mars in the past, must also be found at present at certain sites on the Earth - where they could be studied in detail today. The dry valleys in Antarctica (Wharton *et al*., 1989), the Scabland terrain and deposits in Washington (Edgett *et al.*, 1995), weathered volcanics in Hawaii (Golden *et al.*, 1993) and old lava flows in Canada (Trieman *et al*., 1996) have all been studied as analogs to Martian sites. In fact, a simulant of the Martian regolith (JSC Mars-1) is available (Allen *et al.*, 1997a).

More Meteorites

It can be expected that at least a few more Martian meteorites will be found in Antarctica over the next decade. Obviously the level of effort to collect them should be increased, both in Antarctica and in promising deflation terrain in desert regions (Zolensky *et al.,* 1994).

Lessons Learned

1) Planets can exchange materials (Melosh and Tonks, 1993; Gladman *et al.,* 1996). And this exchange must be significant over a period of 4 billion years. And, during the "cataclysm" 4 billion years ago, it must have been very significant!

2) Mars differentiated early and has not been well-mixed since (Harper *et al.,* 1995).

3) Oxygen isotopes make a good discriminator of planetary bodies (Clayton and Mayeda, 1996). For example, Brachina is not a Chassignite (Crozaz and Pellas, 1983), or rather, Chassigny is not a Brachinite (Prinz *et al.,* 1996).

4) The isotopic study of light elements is important on Mars. We don't know the initial ratios (starting points), but we do know that they evolved by significant loss of Martian atmosphere to space. Isotopic data need to be obtained concurrently for all light elements on aliquots of the same sample split. Additional isotopic exchange experiments need to be performed (Socki *et al.,* 1993; Leshin *et al.,* 1996; Jull *et al.,* 1997).

5) Maskelynite is really plagioclase glass (Ikeda, 1994; Stoffler *et al.,* 1996; Scott *et al.,* 1997).

6) The least expensive way to obtain samples of Mars is to collect them in Antarctica (Yanai, 1997; Cassidy and Rancitelli, 1982).

7) The Public seem to be excited about the possibility of finding life on Mars (Kerr, 1996, 1997).

8) Samples studied in sophisticated terrestrial laboratories can obtain superior analytical data (Drake *et al.,* 1987; Gooding *et al.,* 1989). Data obtained by spacecraft are not precise and accurate enough to solve some important problems (*e.g.* age dating). In addition, in the laboratory, analyses can be performed over and over again, until optimum experimental design is achieved.

9) The composition of the Martian atmosphere can best be determined by measuring the gasses released from glass inclusions in Martian meteorites (Bogard and Garrison, 1998; Garrison and Bogard, 1998).

Unanswered Questions

1) If life existed on Mars, how was it different? (de Duve, 1995)

2) What is the composition of organic matter on Mars? (Wright *et al.,* 1989; McKay *et al.,* 1996; Becker *et al.,* 1997)

3) What was the history of the magnetic field on Mars and did Mars ever have a molten metal core? (Terho *et al.,* 1996; Kirschvink *et al.,* 1997; Collinson, 1997)

4) What is the nature of interaction of fluids on Mars with the rocks? (Gooding, 1992; Plumlee *et al.,* 1993; Griffith *et al.,* 1995; Berthke, 1996)

5) Is it possible to constrain the age of various terrain mapped on Mars, and thus establish an absolute time scale for Martian epochs? (Nyquist *et al.,* 1997)

6) How did the composition of the Martian atmosphere vary with time? (Wright *et al.,* 1990a; Pepin, 1994; Wright *et al.,* 1996a)

7) What is the nature of the Martian mantle (source region of basalts)? Does it contain garnet? Is it depleted in large-ion-lithophile elements? (Gleason *et al.,* 1996; Jones *et al.,* 1997)

8) What is the age of the carbonate mineralization? (Wadhwa and Lugmair, 1997)

9) Which craters on Mars can be related to each of the groups of Martian meteorites? (Barlow, 1997; Mouginis-Mark *et al.,* 1992)

10) Will the thermal emission spectroscopy experiment be able to distinguish and map rock types from orbit? (Hamilton *et al.,* 1997)

Better Instrumentation

Analytical instrumentation has improved in response to the need for understanding Martian meteorites. Pillinger's group has miniaturized mass spectrometers to handle small volumes of gas. Compston's group has invented a whole new line of super-sensitive, high-resolution, ion microprobes to analyze small spots on thin sections. Wasserburg's group and others have greatly improved analytical precision of isotopic ratio measurements. Zare's group has invented laser desorption mass spectrometers. McKay *et al.* and Bradley *et al*. are using the most advanced scanning electron microscopes to look for submicroscopic "nanofossils". And there are many other new instrumental techniques that have been utilized on rocks for the first time, in an effort to learn more about Mars by careful study of Martian meteorites. In 1995, Meyer *et al.* convened a workshop on Planetary Surface Instruments (LPI Tech. Rpt. #95-05).

1) What techniques need to be developed further?

Contamination

Sources of potential contamination are constantly being evaluated and eliminated. (Wright *et al.,* 1992g; Becker *et al.,* 1997; Bada *et al.,* 1997; Jull *et al.,* 1997). Shergotty, Nakhla, Lafayette, Governador Valadares and Zagami all fell in agricultural areas and may have been cut with saws using water and/or kerosene as a coolant! Samples kept in museums may have been touched by many hands! Even in Antarctica, the meteorites are probably exposed to 'melt water', which is certain to introduce some contamination (Becker *et al.,* 1997). Ultra-pure, hot water is now used to clean the processing cabinets and tools at JSC.

1) What can be done in the future to eliminate the potential sources of contamination, so that when something is found in a Martian meteorite we can be sure it came from Mars?